

Experimental Investigation of Concrete Carbonation under Different Conditions

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Abstract

This paper summarized the results of an experimental investigation on the carbonation of concrete under different conditions. Effects of two different conditions on carbonation of concrete were studied: (1) 5% CO₂ concentration and 70% relative humidity, (2) 20% CO₂ concentration and 70% relative humidity. The carbonation depth of specimens were obtained by experimental data and theoretical calculation. The analytical results showed that the carbonation of concrete under low CO₂ concentration can reflect the rule of concrete carbonation very well. The investigations, in this paper, were not only important improvement for the method of artificial accelerated carbonation of concrete, but also the solid foundations for further study on the concrete carbonation.

Keywords

Concrete Carbonation; Carbonation Depth; CO₂ Concentration; Experimental Investigation

Introduction

The durability is a major concern for concrete structures exposed to aggressive environments because the concrete is applied to various civil buildings extensively (NIU Ditao, CHEN Yiqi, YU Shu, 1995). In the recent years, global warming has dramatically increased the atmospheric carbon-dioxide concentration and temperature. As a consequence, carbonation has become one of the most critical durability issues for concrete structures in urban environment. It is well known that carbonation in concrete regularly involves a chemical reaction between carbon dioxide and the products of cement hydration (Saetta A V, Vitaliani R V, 2005). This reaction can lead to a significant reduction in the pH value in the carbonated zone, and may lead to steel depassivation and subsequent reinforcement corrosion. Carbonation-induced corrosion can also increase crack development and decrease concrete durability (Jack M.

Chi, Ran Huang and C. C. Yang, 2002). So carbonation is one of the major factors causing structure deterioration. From the essence, the carbonation of concrete results from both its own characteristics and external environmental conditions (Zhao Y X, Jin W L, 2002). The external environmental conditions include mainly environmental temperature, carbon dioxide concentration, relative humidity etc.. Because of the complexity and randomness of natural climate condition, there are great arguments on the effects of environmental conditions on carbonation of concrete (Y. H. Loo, M. S. Chin, C. T. Tam, K. C. G. Ong, 1994). In the laboratory, the artificial accelerated carbonation test of concrete often is used to reflect the long-term effects of natural carbonation on concrete and in this method, and artificial accelerated carbonation of concrete can be achieved by curing the concrete specimens in favorable environmental conditions for carbonation, i.e. a high CO₂ concentration, while a high CO₂ concentration level also leads to the assessment of concrete carbonation becomes very difficult (Sanjuan MA, Andrade C, Cheyrezy M, 2003). The objective of this study was to investigate the effect of the low CO₂ concentration on the rule of concrete carbonation by artificial accelerated carbonation. An experimental investigation was carried out to study the carbonation of concrete by artificial accelerated carbonation with two different concentration.

Experimental Program

Materials

The concrete mixtures were produced in the laboratory and the cement with a specific gravity of 3.11 kg/m³ was used in all mixtures. The chemical compositions of cement and fly ash are shown in Table 1. The fine aggregate is river sand with fineness modulus of 2.4. The coarse aggregate with a size range

of 5~20 mm was used in all mixtures. The concrete mixtures were designated as shown in Table 2.

A pH indicator solution (made of 1% phenolphthalein in a 70% ethyl alcohol solution) has been prepared in order to measure the depth of carbonation.

TABLE 1 CHEMICAL COMPOSITION OF CEMENT AND FLY ASH (%)

Material	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO
cement	62.53	20.67	6.02	5.03	1.36
fly ash	7.27	51.72	27.16	5.77	1.68

TABLE 2 MIX PROPORTIONS OF CONCRETE

No.	Cement (kg/m ³)	Fly ash (kg/m ³)	Sand (kg/m ³)	Water (kg/m ³)	coarse aggregate (kg/m ³)
T01	365	62	610	195	1151
T02	315	56	714	170	1130
T03	391	69	651	170	1109

TABLE 3 COMPRESSIVE STRENGTH

No.	compressive strength in 28 days (MPa)
T01	41.2
T02	44.7
T03	47.5

Experimental Methods

In this experiment, the specimens of 100×100×400 mm were made by mix proportion, and the specimens were cured at 100% relative humidity for one day and subsequent curing for 28 days at 23°C. The specimens are placed in dry oven and the temperature is kept at 60°C for 2 days before the initiation of the experiments.

Then concrete specimens sealed on both top and bottom surface were placed in the carbonation chamber (as shown in Figure 1) for 20~120 days with two different concentration levels of CO₂ gas (5%, 20%). Testing temperature was kept at 20°C and relative humidity was 70% during the experiment.



FIG 1. CARBONATION CHAMBER IN THIS EXPERIMENT

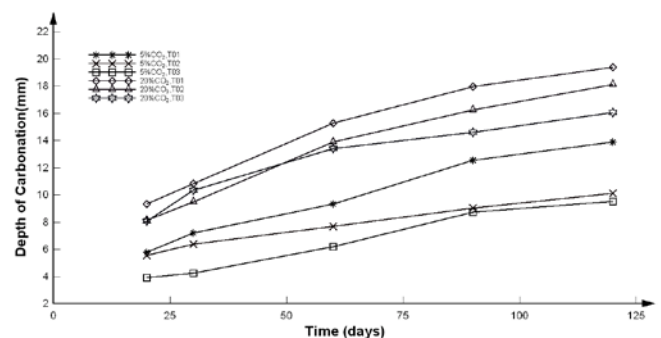
Results and Discussions

The carbonation depth of concrete specimens at the time of 20, 30, 60, 90 and 120 days are presented in Table 4 and Figure 2. It was significant that the

carbonation depth increases with the growth of carbonation time and higher CO₂ concentration level has a higher carbonation depth for all concrete specimens. It can be seen that the carbonation has more obvious effect on the low strength concrete specimens than on high strength concrete specimens. When the time is short (<30 days), the carbonation has little effect on the concrete specimens under 5% CO₂ concentration level. While when the time is up to 60 days, the carbonation has remarkable effect on the concrete specimens under 5% CO₂ concentration level. So the carbonation time should be long enough (>60 days) if an accelerated carbonation test was designed in low CO₂ concentration level.

TABLE 4 CARBONATION DEPTH OF CONCRETE SPECIMENS (mm)

Time (days)	5%			20%		
	T01	T02	T03	T01	T02	T03
20	5.77	5.54	3.89	9.34	8.12	8.06
30	7.21	6.37	4.25	10.83	9.47	10.33
60	9.32	7.69	6.19	15.28	13.88	13.41
90	12.56	9.01	8.74	17.97	16.26	14.59
120	13.87	10.13	9.51	19.38	18.13	16.05

FIG. 2 CARBONATION DEPTH VS TIME UNDER DIFFERENT CO₂ CONCENTRATION LEVELS

Based on the Fick's first law of diffusion, the carbonation depth can be expressed as follows:

$$x = K\sqrt{t} \quad (1)$$

$$K = \sqrt{\frac{2D_{CO_2}}{a} C} \quad (2)$$

Where x is carbonation depth, K is carbonation rate factor, t is carbonation time (year), C is CO₂ concentration, D_{CO_2} is dispersion coefficient of CO₂ in concrete, a is CO₂ uptake in carbonated concrete.

From Eq 1 and Eq 2, a relationship can be written as:

$$t_n = \frac{Ca \times t_a}{C_n} \quad (3)$$

where C_n , t_n are carbonation time and CO₂ concentration in natural condition, t_a , Ca are carbonation time and CO₂ concentration in artificial accelerated carbonation condition.

Based on related research results (Zhang Lingmao and Jiang Wenhui, 1990), the carbonation rate factor in natural condition can be given by

$$K_n = 0.52 - 0.01R_{28} \quad (4)$$

in which R_{28} is concrete compressive strength in 28 days.

The theoretical value of carbonation depth is obtained by the formulae presented above, and the results are shown in Table 5.

TABLE 5 THE THEORETICAL VALUE OF CARBONATION DEPTH (mm)

Time (days)	5%			20%		
	T01	T02	T03	T01	T02	T03
20	6.24	4.62	3.18	12.47	9.24	6.35
30	7.64	5.66	3.89	15.27	11.31	7.78
60	10.80	8.00	5.50	21.60	16.00	11.00
90	13.23	9.80	6.74	26.45	19.60	13.47
120	15.27	11.31	7.78	30.55	22.63	15.56

Figures 3 and 4 show the comparative results for the experimental and theoretical values of carbonation depth under two CO₂ concentration levels.

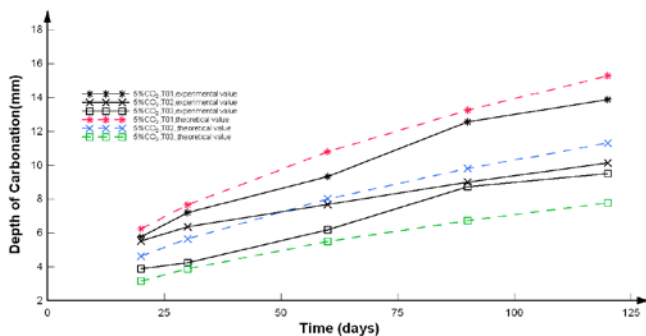


FIG. 3 EXPERIMENTAL AND THEORETICAL OF CARBONATION DEPTH WITH 5% CO₂

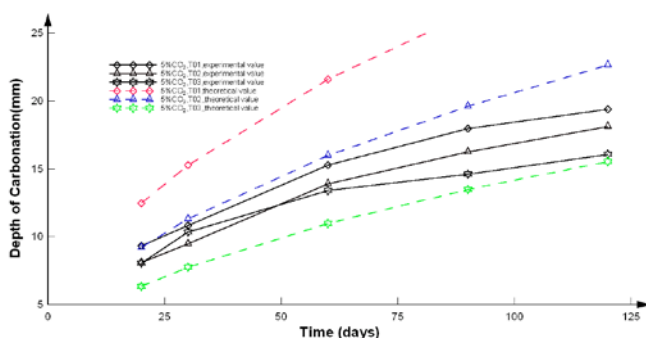


FIG. 4 EXPERIMENTAL AND THEORETICAL OF CARBONATION DEPTH WITH 20% CO₂

Comparing Table 4, 5 and Fig.3, 4, under the low CO₂ concentration level, the relative differences of experimental and theoretical values of carbonation depth lie between 4.03%~22.88%, and the average of relative differences is 11.77%. Under the high CO₂ concentration level, the relative differences lie between 3.05%~57.64%, and the average of relative differences

is 25.94%. Therefore, the carbonation depth of concrete specimens in the accelerate carbonation test with CO₂ concentration level of 5% is closer to the theoretical value compared to CO₂ concentration level of 20%, suggesting that the carbonation results under 5% CO₂ concentration level agree well with the Fick's first law of diffusion (Ming Jing,Zhang Yamei,2010).

Conclusions

The following conclusions can be drawn based on the analysis of the test results of concrete carbonation:

- (1) The artificial accelerated carbonation of concrete under low CO₂ concentration level is practicable when the carbonation time is long enough.
- (2) Because the carbonation results under low CO₂ concentration level agree with the Fick's first law of diffusion, the carbonation of concrete under low CO₂ concentration level can reflect the rule of concrete carbonation very well.

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